Utilizing Off-the-Shelf Parts for the Next Generation of Space Exploration[1]

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Abstract— Common components are evaluated for use in an orbiting Ku-band polarimetric scatterometer that will enable measurements of near-surface wind speeds for over 90% of the ice-free oceans. Designed as a successor to Seawinds, the new design requires two matched RF chains to attain adequate performance. Off-the-shelf DBS (Direct Broadcast System) and telecom components have significant potential to reduce development and equipment costs. However, space flight systems have requirements that are qualitatively different from the commercial or consumer applications for which the majority of new RF products are developed. Furthermore, the 13.402GHz center frequency for scatterometers is somewhat higher than the commercial 12GHz DBS band. Consequently, Jet Propulsion Laboratory (JPL) has taken the next step to test and evaluate these parts, and at present, work reports on RF performance measurements of selected commercial Monolithic Microwave Integrated Circuit (MMIC) components are encouraging and appear suitable for space applications.

For evaluation, two MMIC LNAs (Filtronic, part #LMA246 and TriQuint®, part #TGA8399B) and one mixer (Remec, part #MM84MS-14) were selected. Test fixtures were constructed for the MMIC parts, which were then carefully examined in several test setups. Both dual and single chain configurations were necessary to completely define each component, where tests such as noise figure and gain of the Ku-band amplifiers were completed. Of more importance to the polarimetric application, the stability of relative phase and gain tracking with respect to temperature was extensively characterized in a variety of candidate LNA/mixer configurations. While the initial RF evaluation looks promising, further evaluation of these parts (radiation tolerance, reliability, etc.) will be required for flight qualification.

"Upscreened" Commercial, off-the-shelf (COTS) parts, in space applications are especially encouraging when the possibility of capitalizing on the extensive development for high-volume consumer applications is considered. Other applications for MMIC parts in space could possibly open new doors in the future.

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1. INTRODUCTION

Predicting long-term weather patterns has been a goal of many scientists for a very long time. Orbiting scatterometer instruments such as SeaWinds, currently flying on QuikScat, have greatly improved the amount and quality of ocean winds data available on a continuous basis. Thanks to the recent developments in scatterometry and availability of COTS components to reduce instrument cost and risk, achieving the goal is becoming closer to reality.

Scatterometers are specialized microwave radars that measure ocean backscatter cross-sections, σ_o, at several different azimuth angles. Because σ_o is a function of wind speed and direction, the backscatter measurements can be used to estimate wind at the surface of the ocean [1]. Over time, these measurements have proven to be a critical tool in the study of the climate and have found increased utility in daily weather forecasting.

[1] 0-7803-6599-2/01/$10.00 © 2001 IEEE

Tsai *et.al.*, [2] have proposed using polarimetric scatterometry with measurements from only two azimuth angles rather than the four used in the SeaWinds instrument. Not only do polarimetric measurements reduce some of the ambiguities in the Seawinds type measurements, the halving of the number of "looks" dramatically decreases the field of view required, from 360 degrees to only 180 degrees. This is extremely useful when trying to find accommodations for the instrument on a spacecraft, because it's difficult to find places with 360-degree field of view on a multi instrument platform. The easier accommodations increase the number of candidate spacecraft that can carry a scatterometer, and also reduces the system engineering costs.

Utilizing commercially available parts in the construction of the RF receivers is beneficial because it reduces the Non-Recurring Engineering (NRE) costs associated with custom-designed and mil-spec components [3]. Development of NRE costs alone, is substantially higher when building the parts in-house or hiring contractors, than both buying and qualifying the MMIC parts for flight in this new version. The major difference is the amount of risk involved. For example, if the MMIC parts prove to be worthless after all the testing is complete, the engineer is left with nothing to show. However, if it is a success, then costs have been greatly reduced and the time is takes to see an actual finished product is decreased as well. In the case presented here, the outcome is the latter, with nothing but encouraging data. Therefore, utilizing these components reduces the effort to merely evaluating suitable parts, designing test fixtures, and "upscreening"[2] for space flight applications. This makes the next generation of scatterometers not only more precise with greater efficiency, but cheaper as well.

2. WHY USE POLARIMETRY?

Previous orbiting scatterometers, i.e. NSCAT and SASS, use a "fan beam" system, so called because they employ multiple fixed antennas at different azimuth angles to cast broad shaped beams on the Earth's surface to measure wind [2]. While successful, they had two major limitations: 1) the antennas were large and difficult to accommodate on the spacecraft, and 2) due to beam geometry, backscatter measurements in the region +/- 200km to either side of the nadir track were insensitive to wind direction, thus creating a "nadir gap" in swath coverage [2]. Because of these limitations, wind vector data was difficult to attain. This soon led to a newer technique involving only one dish antenna and two pencil-width beams that make four measurements for every point [1].

This soon led to the realization that using COTS DBS parts in combination with the new polarimetric technique would not only reduce the problems of the past but also alleviate much of the high price tag associated with previous scatterometers.

3. EVALUATION OF COMPONENTS

Early in the conceptual design process, a key area of the scatterometer identified for possible COTS insertion was the Low Noise Amplifier (LNA) and first mixer. The rapid growth of consumer DBS has led to a large number of high performance MMIC components being available. The first step towards evaluating the concept of COTS components in the front end for a polarimetric receiver was to find components suitable for use in a space flight qualified system. These components not only have to meet the usual performance criteria, but have to prove themselves suitable, primarily in terms of reliability, for a spacecraft system where repair is not an option. The components ultimately selected are evaluated against numerous criteria such as gain, noise figure, ease of use, and power consumption. Finally, an evaluation of the reliability and manufacturing traceability are used to determine if the components are suitable for flight applications.

The LMA246 amplifier from Filtronics was one of two amplifiers chosen for evaluation. This part has heritage, which was used as a prototype in an engineering transceiver application that the design engineer used while working at another facility and appeared to be suitable.[3] The MMIC is small, 3.15mm X 2.5mm, and single bias voltage of +6Volts, which simplifies the design of a system using the part.

The second amplifier chosen for evaluation was a TriQuint® TGA8399B. The specified operating band of this amplifier is 6 - 13GHz, which is just below the operating frequency of the polarimetric design of 13.402GHz. While the manufacturer did not provide guaranteed performance specifications at this frequency, the broadband nature of the component made it likely that the part would have acceptable performance in our receiver application. This part was also attractive due to the lower noise figure (1.75 dB), compared to the Filtronic part (2.2 dB). At the early stages of conceptual design, noise figure was of concern, as the polarimetric radar is looking for signals much lower in level than the primary "co-pol" backscatter. Furthermore, the TriQuint® part requires fewer bias components[4], making it even more attractive.

[2] "Upscreening" is a detailed process required for all flight used parts not space qualified. It involves many hours of various types of testing, including verifying substrate bond strengths and structural integrity of package, removing chips with mechanical defects such as microscopic cracks in the device, etc. Typical failure rate during "upscreening" is 50%. Therefore, it is a rare event for "unscreened" COTS parts to be used in flight applications.

[3] Heritage has high priority, provided the part has been successful.

[4] Many components require an external resistive network and capacitance along with their chip, whereas the TGA8399B amplifier only requires a single capacitor. Less parts means less tuning and chance for failure.

Finally, a Remec MM84MS-14 Ku-band mixer was selected to complete the "front end". Its specifications indicated that was both in-band and has approximately 7.5dB of conversion loss at the operating frequency of 13.402GHz. A significant feature of this mixer is the low LO drive level. Most of the MMIC COTS mixers that are on the market require drive levels around +17dBm, while this component only requires +10dBm for a comparable performance. A tradeoff however, was the actual size of the chip (8.13mm x 15.24mm), which is much larger than a typical size (1.48mm x 1.48mm) of a mixer at the +17dBm drive level. The lower drive is important due to power constraints on the spacecraft subsystems, and the chance that a higher LO power level would aggravate LO leakage. The scatterometer doesn't require extreme dynamic range (the returns are at most 10 to 15dB above the noise floor, before compression), so the 1dB compression point of 5 dBm was sufficiently high.

4. TEST FIXTURES

Once the components were chosen, test fixtures for two of the three parts (TriQuint® and Remec parts) were created so evaluation of all the components could be completed. The Filtronic amplifier was mounted in a test fixture by an outside manufacturer. Fixture design was a detailed process involving many factors, such as the physical size of the MMIC chips, dimensioning and tolerancing, etc. Figure 1 and Figure 2 are photographs of the finished holding fixture and part for the Remec mixer and TriQuint® LNA fixtures respectively. After mounting in the fixtures, preliminary tests were conducted to verify that the components met the manufacturer's nominal specifications.

channel would process H polarization returns and the other V polarization returns. The polarimetric "signature" of greatest interest is actually a correlation between the two signals, and the relative phase of the two channels is very important. Therefore, the primary objective for testing the dual RF receiver pair is to determine the receiver-to-receiver phase tracking capability of two receiver front-ends, each comprised of two COTS amplifiers and one COTS mixer. Preliminary conceptual instrument design had established working requirements for absolute phase shift within +/- 10 degrees, over –30 to +80 degrees C of each other, and within +/-4 degrees in phase differential between two channels at each temperature.

Prior to double string testing, the strings were evaluated in a single string configuration to characterize their general performance. A photograph of a single receiver string utilizing the Filtronic amplifiers can be seen in Figure 3. Several values of padding (3, 5, and 8dB) between components were utilized to obtain a better VSWR (from 2:1 to 1.5:1). Without the pads, the phase of the output varied significantly, most likely due to the reactive input and output impedances of the amplifiers. Differential phase variations were reduced by 2 degrees after adding the pads. During this testing, some problems were encountered with spurious oscillations in one of the Filtronic amplifiers. A spare amplifier was not available, so tests were conducted using the anomalous amplifier. While the output of the dual Filtronic amplifier was not as good as the one with two stable amplifiers, the strings continued to track in phase and gain over several trials, and, in fact, met the nominal requirements.

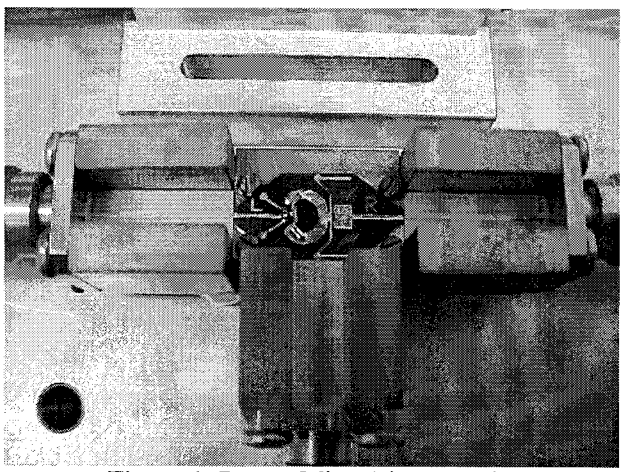

Figure 1: Remec Mixer Fixture and part.

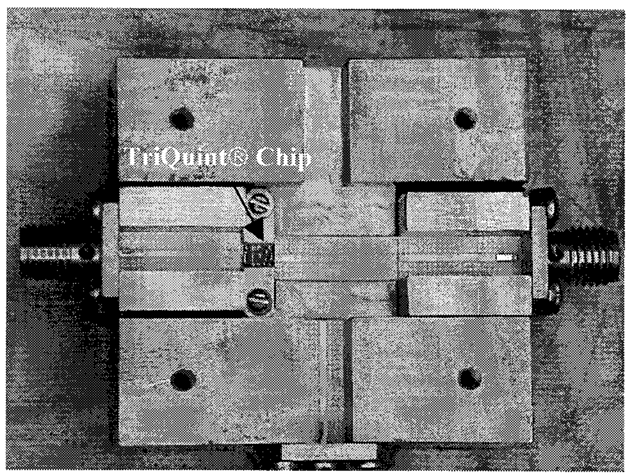

Figure 2: Top-view of TriQuint® Amplifier and fixture.

5. RF RECEIVER TESTING

The components were tested in a dual receiver front-end configuration, representing the expected use where one

The phase tracking was measured by feeding both input channels with a single Ku band signal and passing the LO of one channel through an adjustable waveguide phase shifter (HP P885A). The outputs of the strings were mixed in a phase detector, and the phase shifter adjusted for a null, indicating quadrature at the outputs. After null was achieved, the strings were subjected to three repeatable temperature cycles from -30°C to +80°C in 10°C increments. At each temperature, the gain of the amplifier strings were recorded using an HP438A, and the phase of each string was measured by nulling out the drift in phase with respect to ambient, utilizing the phase shifter.

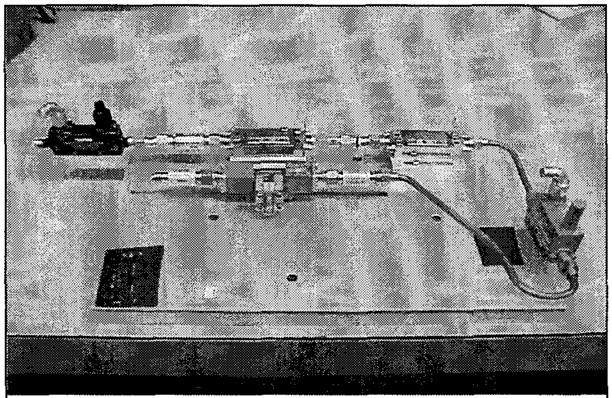

Figure 3: Dual Amplifier, Single Receiver String

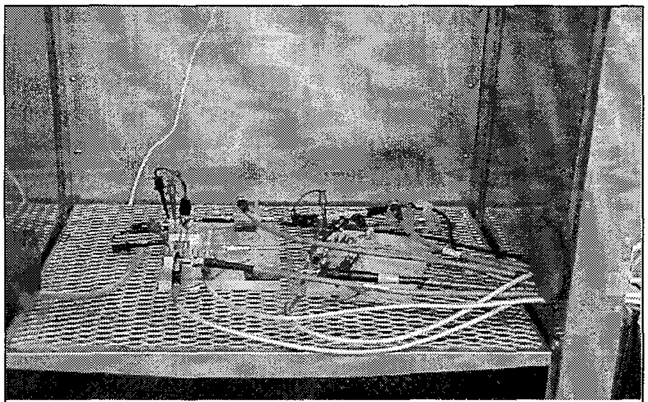

Figure 4: Dual Amplifier, Dual String under Test

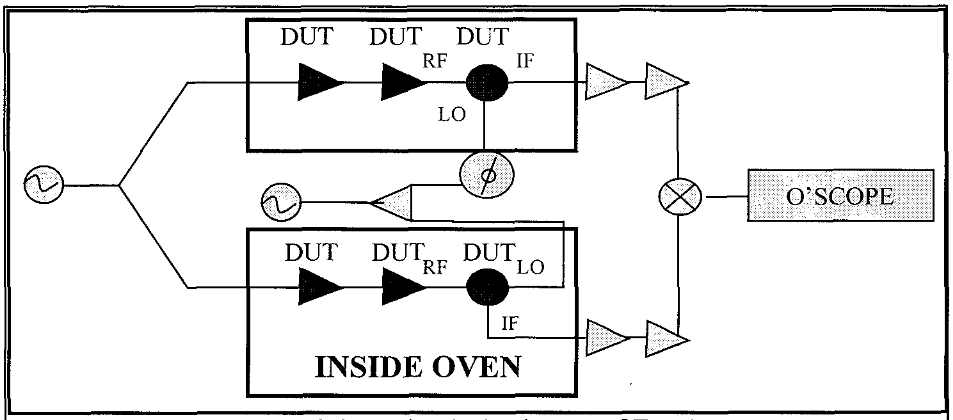

Figure 5: Schematic Block Diagram of Test Setup.
*DUT = Device Under Test

All tests were performed with a dynamic range of 10dB by adjusting system power levels to match component performance. Measurements over a wider dynamic range were not performed due to test set-up limitations. However, the testing was performed at levels greater than 50dB higher than anticipated for actual use. This was done in order to view worst case deviations, the results of which can be seen in Figures 6 and 7.

The receiver pair utilizing the Filtronic parts spanned approximately +/-6 degrees in phase over the full temperature spectrum and a maximum differential of 3.5 degrees at each temperature[5], as seen in Figure 6. This is well within the nominal requirement.

Using the TriQuint® parts proved to be as good as the nominal requirement of 20 degrees, with the change in phase between the two receiver strings to be within +7 and –13 degrees. This is most likely due to two reasons, 1). The amplifier was operating out of band, and 2). There was an anomaly in the amplifier set-up that was never located due to time constraints[6]. However, because this amplifier was chosen as being purely experimental, (i.e. determining if the amplifier, which has superior qualities but is out of band, would produce comparable results to the in-band Filtronic amplifier), results taken were used only as a basis for reliability of the part at 13.4GHz, and has no bearing on the

[5] It should be noted that each 10-degree change in phase represents approximately a 0.06mm change in wavelength in free space at 13.4GHz and somewhat less in a dielectric.

[6] The anomaly was seen in the form of a jump in the output power level at around 40degree C. While many things were tried to correct this, no solution was discovered in the limited time frame allotted by the project.

overall evaluation[7].

A secondary objective is to have the gain of the two, receiver strings track within +/-4dB of each other over the full temperature range

When measuring gain for the Filtronic amplifier set-up, it has been shown, through results presented here, that the gain of the Filtronic amplifier is within specification. The Filtronic amplifiers change approximately 2.5dB over the full temperature spectrum, and approximately 3dB between strings at each temperature, as seen in Figure 6. These results demonstrate that it is possible to achieve the accuracy needed for phase tracking, while maintaining comparable gains between the two strings utilizing commercially available parts.

After determining that the receiver chain with the oscillating amplifier was still functioning within specifications, the dual amplifier, dual receiver chain configuration was assembled. With two of the same chains working side-by-side, as shown in Figure 4, the system appeared more stable with respect to phase and gain. Three separate trials were completed for verification that the results were repeatable. While the single chain alone produced a phase variation of +/- 8 degrees over the full temperature range, the dual receiver string improved with a phase variation of only +/- 6 degrees. This is mostly due to the reverse isolation of the second amplifier in each string, which tends to minimize the phase mismatch in the cables. Figure 7 illustrates the differential phase data recorded over temperature.

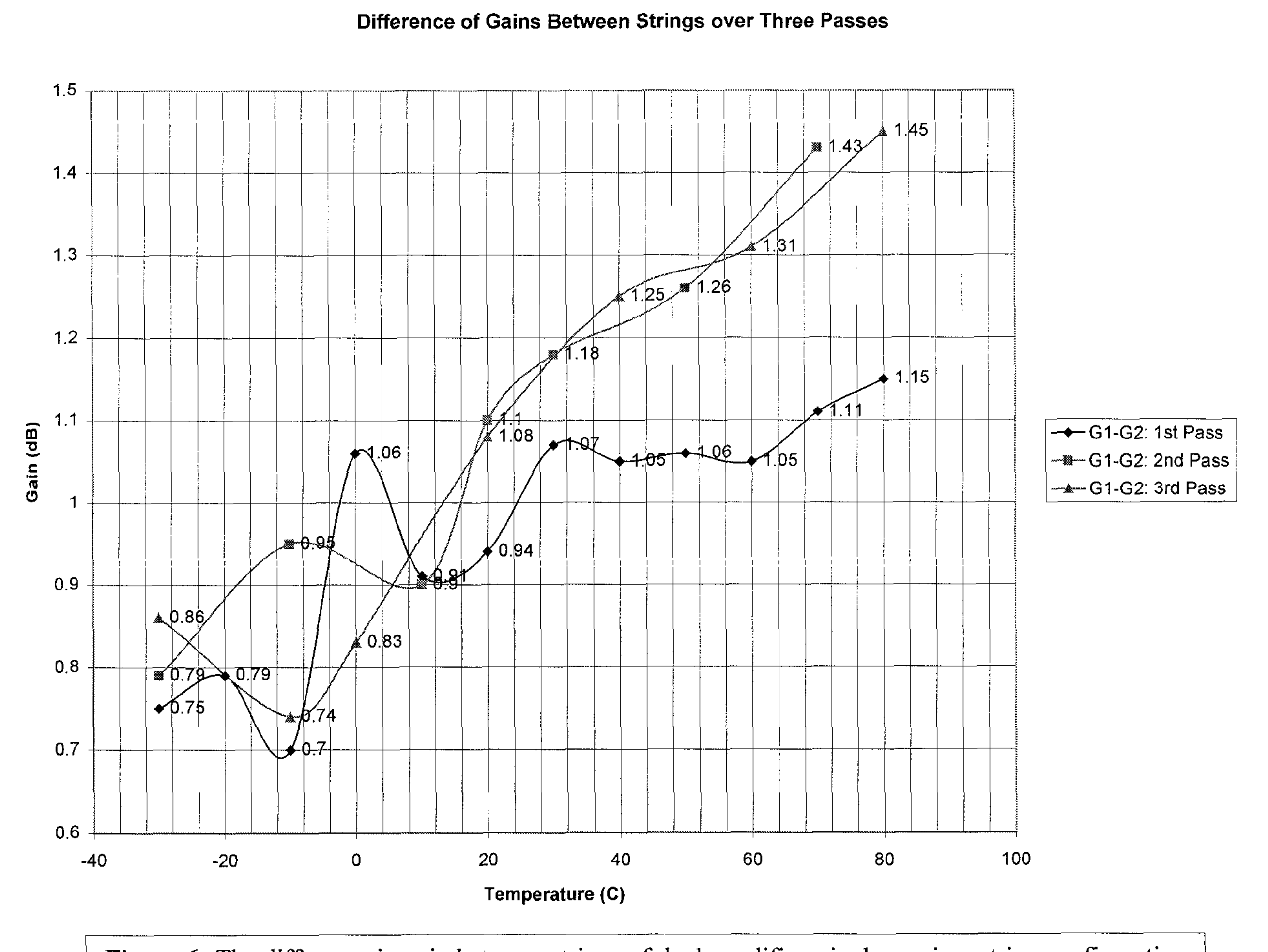

Figure 6: The difference in gain between strings of dual amplifier, single receiver string configuration

[7] Results presented will only represent output from the strings utilizing the in-band Filtronic parts and not from the out of band TriQuint® parts. The TriQuint® amplifiers are only brought in for comparison purposes between two sets of MMIC parts.

6. CONCLUSIONS

After experimenting with several test set-ups and power levels, it has been determined that using commercial off-the-shelf (COTS) Direct Broadcast System (DBS) parts, specifically two Low Noise Amplifiers (LNAs) and one mixer, is a reliable and extremely viable solution to completing the task ahead. According to Duncan Young, Director of marketing for board designer DY 4 Systems in Kanata, Ontario, COTS remain a "little market niche," but has transformed the business environment [4]. These components, are not only readily available, but are both smaller and inexpensive as well. Even with these characteristics aside, these parts have proven to have better performance than the components used in the past. With all four of these factors being positive, the only logical solution is to continue experimenting with COTS.

Upon close examination of the results presented here, it can be shown that the results are equivalent, if not better in some areas, than its predecessor, SeaWinds, for the Filtronic amplifiers in combination with the Remec mixer. Innovation and cost saving measures were employed to obtain repeatable results quickly and cheaply, so preliminary experimental results could be taken. As a result, more evaluation is needed to determine the results in a more realistic environment, and whether or not these COTS components will pass all critical requirements in the "upscreening" process.

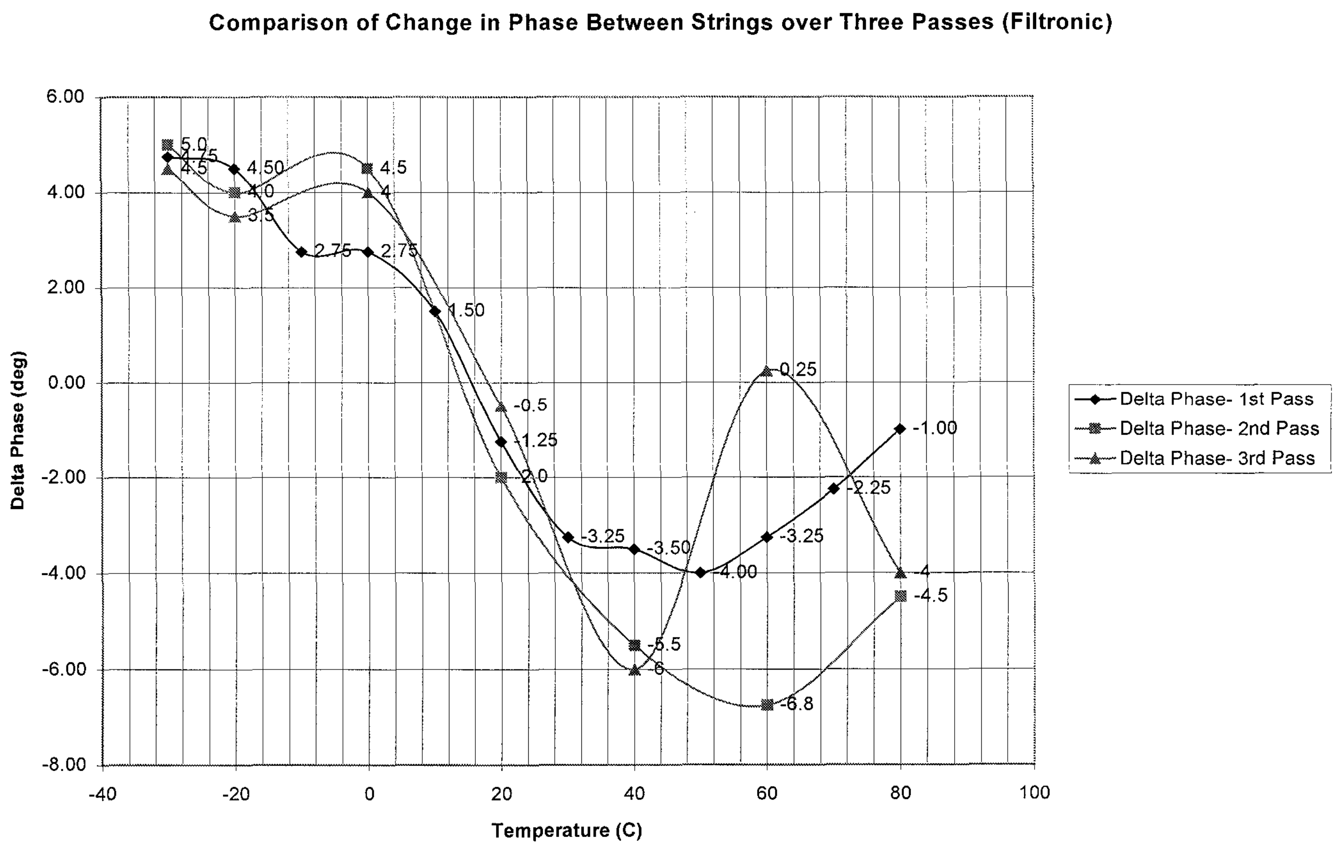

Figure 7: Graph of change in phase with respect to ambient over temperature for all three passes.

While this paper was being written, experiments have been performed on an airborne polarimetric scatterometer. While the results have yet to be calibrated, the polarimetric correlation signature is obvious, and is of the right general magnitude and shape to assess the viability of polarimetric scatterometery.

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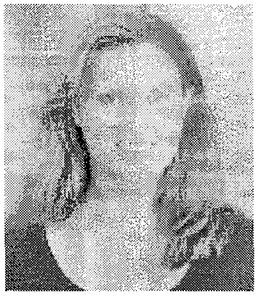
References

[1] M.W. Spencer, C. Wu and D.G. Long, "Tradeoffs in the design of a spaceborne scanning pencil beam scatterometer: Application to SeaWinds, "IEEE Transactions Geoscience Remote Sensing, Vol. 35, pp 115-126, Jan. 1997.

[2] Wu-Yang Tsai, Son V. Nghiem, James N. Huddleston, Michael W. Spencer, Bryan W. Stiles and Richard D. West, "Polarimetric Scatterometry: A Promising Technique for Improving Ocean Surface Wind Measurements from Space," IEEE Transactions on Geoscience and Remote Sensing, Vol. 38, No. 4, July, 2000.

[3] John McHale, "Despite COTS, custom electronics are still vital on the battlefield," Military and Aerospace Electronics, Vol. 11, Issue 7, July 2000.

[4] John Rhea, "COTS has not had its day, board industry expert tells COTScon," Military and Aerospace Electronics, Vol. 11, Issue 7, July 2000.



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